Chapter 8
Anchoring Structures

8-1. General

This chapter provides guidance on the design of anchoring structures to rock. Structural anchors are often used to improve the stability of existing structures but, generally, should not be used as a primary means to stabilize new, large mass concrete structures. If a situation exists where anchors appear to be necessary (space limitations and/or economics dictate their use), prior approval from CECW-ED must be obtained. Two such Corps projects are the Bay Springs Lock on the Tennessee-Tombigbee Project and the Bonneville Lock on the Columbia River. Described below are considerations that dictated the use of tensioned structural anchors for these two projects.

a. Bay Springs Lock was located in a deep-rock excavation so a considerable savings was achieved by anchoring the lock walls to the rock. This reduced the amount of rock excavation and the amount of mass concrete. This project was designed by the Nashville District.

b. Bonneville Lock and the upstream approach channel wall are in close proximity to a railroad. So, to avoid relocating the railroad it was determined the most economical design was to use structural anchors to stabilize the walls. This project was designed by the Portland District.

Wanapum Dam is not a Corps project but is included in the discussion to demonstrate that tensioned structural anchors are occasionally used by others for new designs. Wanapum Project included a hydropower station designed to provide for six future generating units. To reduce initial outlay, only the intakes for these six future generating units were constructed. The intakes, however, lacked stability so the most practical and economical solution was to use tensioned structural anchors to stabilize the monoliths (Eberhardt and Veltrop 1965).

It should be noted that untensioned structural anchors are commonly used in designs of new structures to stabilize thin concrete members on or against competent rock. Thin concrete members include walls, chute slabs, stilling basin slabs, and paved channel slabs (paragraph 8-2.b). For such uses, prior approval from CECW-ED is not required.

8-2. Methods of Anchoring Structures to Rock

a. *Tensioned structural anchors.* Inclined, tensioned structural anchors are effective in increasing the stability of structures by improving factors of safety for sliding and uplift, and improving the resultant location. The number, orientation, and capacity of anchors should be based on engineering considerations and stability requirements. The process of installing tensioned structural anchors is one of drilling holes across potential failure planes, inserting the tendons, grouting the bond length (length of tendon that is bonded to the primary grout and capable of transmitting the applied tensile load to the surrounding rock), and jacking the live end of the anchor to induce an active tensile load in the free stressing length (length of tendon that is not bonded to the surrounding ground or grout during stressing) of the anchor. The tensile force induced in the free stressing length of the anchor loads the potential failure plane with a compressive stress normal to the failure plane and for inclined anchors, a horizontal component that reduces applied shearing loads. Allowances are made in the jacking load for anticipated losses such as relaxation of the tendons, seating losses, creep, and foundation consolidation. There are a large number of systems to choose from with the primary considerations being cost and corrosion protection. Generally, fewer higher capacity anchors are less expensive than more smaller capacity anchors. Single, high-strength steel bars have the smallest capacity of tensioned anchors, while steel strand is used when large capacity anchors are needed. Single bars provide less force because they have a lower working stress than strands. The three most common types of anchor systems are the hollow groutable anchors, the solid continuously threaded bar anchors, and strand anchors. Following is a brief description of each system.

(1) The hollow-groutable anchor system is furnished with anchor cones and a threaded jacking or torquing end. The hollow anchors are grouted in place after tensioning.

(2) The threaded-bar anchor system is tensioned with a center pull jack. A special threaded nut is used for locking- in the applied tension. The threaded bars may be secured in two-stage cement grout or fast- and slow-set polyester resin grouts. Long-term creep of polyester resin has been a concern that stems from laboratory tests at high-bond stresses. Generally, creep at normal working-level stresses will not be a problem.

(3) The strand anchor system is a seven-wire type having a center wire enclosed tightly by six helically placed outer wires. Strand anchors use single- or two-stage grouting with the single-stage grouting being referred to as an unbonded anchor, while the two-stage grouting procedure is referred to as a bonded anchor. The free stressing length of bonded anchors are grouted after the anchor has been stressed.

b. Untensioned structural anchors. Untensioned anchors should not be used to improve sliding stability since they may require excessive displacement before becoming effective. Where the use of untensioned structural anchors is considered acceptable, precaution should be taken in the design to limit the movement required to mobilize the anchor. Untensioned structural anchors are often used for the following situations.

(1) Walls. Anchored walls should be considered in areas where the rock is strong and firmly in place but is subject to surface expansion and exfoliation upon exposure. The concrete lining serves to limit the surface deterioration and to protect it against erosion from flowing water. The lining should be anchored adequately by untensioned structural anchors grouted into drilled holes in the rock. Unless the rock mass is essentially free of jointing, the anchorage should extend deep enough to engage a sufficient mass of rock for stability with a factor of safety where the anchored portion is assumed to be separated from the adjacent rock by continuous cracks. In some cases, the existence of definite slip planes dipping into the channel may require deeper anchorage near the top of the wall. Anchors may be installed at any inclination, except inclinations less than 5 deg from horizontal which should be avoided due to difficulties with installation. Horizontal and upwards-sloping anchors require specialized grouting techniques. Drainage should be provided to reduce the hydrostatic pressure behind the wall as much as practicable. Drain holes drilled into rock with outlets through the concrete generally provide the best and simplest system. The drain holes are sloped down a little toward the outlet and should be deep enough to adequately drain those cracks within that rock mass necessary for stability, plus the area immediately behind the mass. In cold climates, concrete thickness required for frost protection of poor rock may determine the wall thickness. Otherwise, the anchorage and concrete lining are designed to withstand the reduced hydrostatic pressure.

(2) Slabs. Anchored slabs on rock are designed to withstand uplift and other probable forces with an ample factor of safety. If the slab is on suitable rock, the slab can be anchored with untensioned structural anchors grouted in holes drilled into the rock. The holes shall have a sufficient depth to engage a mass of rock the submerged weight of which will withstand the net upward forces, assuming the mass of rock bounded by a 90-deg apex angle at the bottom with allowance for overlap from adjacent anchors. Drain holes drilled into the rock and discharging through the slab can reduce unbalanced hydrostatic uplift. Depth and spacing of drain holes should be determined by consultation with the geotechnical engineer. The holes should be inclined at a small angle from normal to the slab so that their outlet end is downstream from their inlet end to avoid a possible increased uplift from flowing water. A pervious drainage blanket under the slab with transverse perforated drain pipes discharging through the slab may be economical where a blanket is needed to protect the foundation from freezing.

8-3. Tensioned Structural Anchor Loads

For inclined structural anchors, the vertical component adds to the frictional resistance, and the horizontal component acts in the same direction as the resisting forces. The horizontal component should be treated as an applied load.

Adding the horizontal component to the frictional resistance is not logical since the frictional resistance is a function of the normal loading and angle of internal friction, while the horizontal component is related only to tendon load and inclination of the tendon. These applied loads occur immediately upon stressing the anchors and are not associated with deformations accompanying the development of frictional resistance. Thus, it should be considered an applied load that induces shear stresses along potential sliding planes opposite in direction to those due to downstream forces on the structure.

Rehabilitation of existing structures should examine a range of anchor forces varying from the force needed to meet Chapter 3 stability requirements to minimal forces needed to meet the requirements discussed in Chapter 6. A check should be made to ensure that the horizontal component is never so large as to cause upstream sliding. An example might be that the horizontal component applied to a dam is equal to or larger than the reservoir load on a dam. This raises the question of possible upstream sliding should the reservoir ever be evacuated.

8-4. Structural Anchor Design

a. Tensioned structural anchors. PTI 1996 provides guidance in the application of permanent and temporary prestressed rock and soil anchors utilizing high-strength prestressing steel (includes bars and strand guidance). The recommendations do not deal with the design of anchored structures in general, but are limited to considerations specific to the prestressed ground (soil or rock) anchors. Design, materials, fabrication and handling, installation, and performance testing of **permanent** tensioned structural anchors should be in accordance with PTI 1996 subject to the following exceptions.

(1) PTI Chapter 3.0, “Specifications and Responsibilities” is not applicable because the structural anchors are a part of a larger Corps project and, as such, the structural anchors are included as a part of the contract documents.

(2) PTI Chapter 4.0, “Materials” requirements shall be used for prestressing steel (strand, bar, indented strand, epoxy-coated strand, epoxy-coated bar), anchorages, couplers, centralizers and spacers, corrosion inhibiting compound, bond breaker, sheath, tendon bond-length encapsulations, heat-shrinkable sleeves, grout tubes, anchor grout, cement grout, and polyester resin grouts.

(3) PTI Chapter 5.0, “Corrosion Protection,” provides guidance for two classes of corrosion protection. Class I, encapsulated tendons, is often referred to as double corrosion protection while Class II, grout protected tendons, is often referred to as single corrosion protection. Class I corrosion protection shall be used for the anchors.

(4) PTI Paragraph 6.4.2 discusses fully bonded and unbonded anchors. Fully bonded anchors are required and shall be grouted in two stages, i.e., first stage (primary) is to grout the bond zone, and the second stage is to grout the free length after the anchor has been stressed.

(5) PTI Paragraph 7.4 discusses waterproofing rock-anchor drill holes. Provisions in this paragraph are a requirement.

(6) Soil anchors are not allowed without prior approval from CECW-ED.

b. Untensioned structural anchors. There is no industry standard for the design of untensioned structural anchors. Therefore, the guidance presented here shall be followed. To limit the movement required to mobilize the anchor, use ample-sized anchors. The anchors shall be ASTM grade 60 bars designed in accordance with EM 1110-2-2104. The purpose of this requirement is to minimize movement of the structure.

c. Bond length for tensioned and untensioned structural anchors. The required anchorage length is based upon tendon load, diameter of the tendon hole, type of tendon system, and the bond strength between the surrounding material and grout. The bond lengths calculated below should be verified by performing pull-out tests utilizing tendon systems and drill-hole sizes matching those used by the contractor. If the foundation is variable, pull-out tests should be performed in areas representative of all site conditions and bond lengths adjusted accordingly. The embedment, and/or embedment with hooks, in the concrete for untensioned structural anchors should be in accordance with the requirements of EM 1110-2-2104. Embedment length should not be confused with the anchorage bond length of the tendon. Bond lengths for tensioned and untensioned structural anchors can be estimated by using the largest value resulting from the computations in paragraphs (1), (2), or (3) below.

(1) Bond between tendon and grout

$$L = \frac{Load}{\phi \; \pi \; d_b \, f_{bu}} \qquad (8\text{-}4)$$

where

L = bond length

Load = ultimate load for untensioned anchors and design load for tensioned anchors

d_b = diameter of tendon

f_{bu}* = ultimate bond strength between tendon and grout (For design, $6\sqrt{f_c}$ where f_c is the strength of grout may be used)

Phi* = 0.9

* f_{bu} must be verified by tests as specified in PTI 1996 paragraph 10.1 Appendix A - Prestressing Strand Bond Capacity Test.

** Phi is not included in tensioned anchor design.

(2) Bond between grout and rock

$$L = \frac{Load}{\phi \; \pi \; d_h \, f_{cu}} \qquad (8\text{-}5)$$

where

L = bond length

Load = ultimate load for untensioned anchors and design load for tensioned anchors

d_h = diameter of drilled hole

f_{cu} = ultimate bond strength between grout and rock, or c, whichever is less (PTI Table 6.1 f_{cu} values may be used for design)

c = cross bed shear value in rock in the direction of pull out

Phi* = 0.9

* Phi is not used for tensioned anchor design.

(3) Rock-mass shear failure

(a) Tensioned structural anchors. With all tensioned structural-anchor systems, a major consideration is determining how deep to install the anchors. An anchor system that is too shallow may cause tension and cracking to occur along potential failure planes in the foundation, and a system too deep is uneconomical. PTI recommends normal bond length not less than 3.0m (10ft) for bars and 4.5m (15ft) for strand. Bond lengths greater than 10m (35ft) are normally not used. PTI recommends free stressing lengths to be at least 3.0m (10ft) for bar tendons and 4.5m (15ft) for strand tendons. Center-to-center spacings between bond lengths shall be at least 1.5m (5ft) unless unusual circumstances dictate. Bond lengths should be staggered.

(b) Untensioned structural anchors. For untensioned structural anchors, rock-mass failure will not normally govern design. Where the foundation consists of weak or cracked rock, a rational analysis should be performed to ensure adequate embedment length. This analysis should be performed in accordance with the requirements given in EM 1110-2-2400.

d. Anchorages for tensioned structural anchors. Anchorages shall be a combination of either a steel-bearing plate and wedges, or a steel-bearing plate with a threaded anchor nut. The corrosion protection of the tendon in the vicinity of the anchorage shall be carefully designed and built for a proper protection in this most critical zone. It is important to properly detail the region under the anchorage. Following tensioning of large tendons, tremendous load will enter the bearing plate and be distributed to the concrete. Careful attention must be given to the design of the bearing plate dimensions as well as the localized stress concentrations that can occur in the concrete at the edges and/or immediately beneath the bearing plate. An example of detail that must be given to this problem is discussed in the Stewart Mountain Dam Report (Bureau of Reclamation 1991).

8-5. Stressing, Load Testing, and Acceptance

Field tests shall be performed before and during the installation to verify the adequacy of the anchor system and installation procedures. Tests before installation shall be used to check the performance of selected drilling method, conformability of hole size and drift tolerances, adequacy of assumed bond strengths between grout and rock, grout and concrete, and grout and tendon. Tests during installation should be adequate to ensure that anchors are installed in accordance with the requirements of the plans and specifications and that the ultimate capacity of the tendon can be developed. The number of tests required depends on the site-specific information including drilling conditions, type and/or size of tendons, and complexity of foundation formation and material. Field stressing and testing are required for every tensioned structural anchor to stress and to lock off the tendon at its specified load and to ascertain that the anchor meets the acceptance criteria. All testing procedures and acceptance criteria shall be in accordance with PTI 1996.

8-6. Monitoring Structural Anchor Performance

Since Class I corrosion protection is required for tensioned anchors which results in a fully bonded anchor, and untensioned anchors are installed with a single grouting process which also results in a fully bonded anchor, long-term monitoring of anchor systems is limited. It is assumed that fully bonded anchors are maintenance free because the alkalies in the grout provide extra corrosion protection, the entire anchor is not lost if a portion of the anchor fails, and localized, small movements can mobilize reserve capacity in the anchor. Inspection of the structure and monitoring its behavior is the only sure way of monitoring fully bonded, structural anchor performance. Provisions are being developed that will allow measurements of galvanic action within the anchor system. These procedures are still in the developmental stage but should be investigated by the designers if they need assurance that an anchor system remains functional.